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6. AUTHOR(S) Alexander Gaeta				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Cornell University School of Applied and Engineering Physics Ithaca, NY 14853			8. PERFORMING ORGANIZATION REPORT NUMBER	
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13. ABSTRACT (Maximum 200 words) We have investigated the linear and nonlinear optical properties of photonic crystal fibers. Our efforts have included: 1) the development of a dispersion characterization technique based on the use of femtosecond laser pulses and its application to microstructured and photonic band-gap fibers; 2) theoretical modeling of supercontinuum generation in small-core microstructured fibers; 3) effective delivery of femtosecond nanojoule pulses through meter-long lengths of large-core microstructured fiber.				
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I) Statement of Problem Studied: We have investigated the linear and nonlinear optical properties of photonic crystal fibers.

II) Summary of Most Important Results

We have investigated the linear and nonlinear optical properties of photonic crystal fibers. Our efforts have included: 1) the development of a dispersion characterization technique based on the use of femtosecond laser pulses and its application to microstructured and photonic band-gap fibers; 2) theoretical modeling of supercontinuum generation in small-core microstructured fibers; 3) effective delivery of femtosecond nanojoule pulses through meter-long lengths of large-core microstructured fiber.

III) List of Manuscripts:

- 1) D. Ouzounov, D. Homoelle, A. L. Gaeta, W. Zipfel, W. W. Webb, J. A. West, J. C. Fajardo, and K. W. Koch, "Dispersion measurements of microstructured fibers using femtosecond laser pulses," *Opt. Commun.* **192**, 219 (2001).
- 2) D. G. Ouzounov, K. D. Moll, M. A. Foster, W. Zipfel, W. W. Webb, and A. L. Gaeta, "Delivery of nanojoule femtosecond pulses through large-core microstructured fibers," *Opt. Lett.* **27**, 1513 (2002).
- 3) A. L. Gaeta, "Supercontinuum generation in microstructured fibers," *Opt. Lett.* **27**, 924 (2002).
- 4) J. N. Ames, S. Ghosh, R. S. Windeler, A. L. Gaeta, and S. T. Cundiff, "Excess noise generation during spectral broadening in microstructure fiber," *Appl. Phys. B* **77**, 279 (2003).

IV) Conference presentations:

- 1) A. L. Gaeta, "Nonlinear interactions in microstructured, band-gap, and hollow fibers," (Invited) delivered at the Summer School on New Frontiers in Optical Technologies, Tampere University of Technology, Tampere, Finland, August 2003.
- 2) A. L. Gaeta, "Nonlinear interactions in microstructured, band-gap, and hollow fibers," (Invited) delivered at the Gordon Research Conference on Nonlinear Optics and Lasers, New London, NH, July 2003.
- 3) A. L. Gaeta "Origin of supercontinuum generation in microstructured fibers," delivered at the 2002 Annual Meeting of Laser and Electro-Optics Society, Glasgow, Scotland, UK.
- 4) A. L. Gaeta, "Nonlinear propagation of femtosecond pulses in microstructured fibers," delivered at the Ultrafast Optics Meeting Montebello, Quebec, in July 2001.
- 5) A. L. Gaeta "Supercontinuum generation in microstructured fibers," delivered at the Workshop on Ultrafast Nonlinear Optics and Semiconductor Lasers, Cork, Ireland, in September 2001.

V) Scientific Personnel: Two PhD candidates (Dimitre Ouzounov and Faisal Ahmad) received support under this grant. Dr. Ouzounov received his doctoral degree in 2003.

VI) Scientific Progress and Accomplishments

The recent development of a new class of optical fibers known as a photonic crystal fibers (PCF's) allows for unprecedented flexibility to engineer the light propagation characteristics of these waveguides. PCF's are fabricated from fused-silica glass such that the cross-section consists of a periodic air-hole lattice in which a "defect" mode is introduced, for example, by eliminating one of the air holes in the fabrication process. We have studied two different classes of PCF. The first consists of a solid glass core that is surrounded by an air-glass lattice and is known as a microstructured fiber. Such a fiber effectively guides light in a manner analogous to a conventional step-index fiber, that is, via total internal reflection. Nevertheless, it has the potential to achieve single-transverse-mode operation over an extremely wide range of wavelengths (e.g., from 400-1600 nm) or to shift the zero-dispersion point of the fiber down to the visible regime. The second class of fiber consists of a hollow-core defect in which light is guided via diffraction. This fiber is also known as a band-gap fiber (BGF) since it guides light only over a limited range of wavelengths. BGF's offer enormous promise for telecommunications since they could potentially result in highly reduced scattering losses and optical nonlinearities. However fabrication of these fibers has posed an enormous challenge and only now are high-quality samples available for study and characterization. BGF's also offer numerous intriguing possibilities for applications outside of telecommunications since they allow for the interaction of highly localized of light fields with gases injected into the core over extremely long length scales.

In our research effort supported by ARO, we developed a highly effective technique to characterize the dispersion of microstructured fibers, even under conditions in which the fiber is multimode. Our technique utilizes femtosecond ultrafast optics and is analogous to the pulse-delay method and can be used to perform dispersion measurements on fibers as short as a few centimeters. We used this technique to characterize a variety of MF's and PBF's.

We also performed theoretical study of the propagation of femtosecond pulses in MF under conditions similar to those of these recent experiments in which the process of supercontinuum generation occurs and we find that higher-order dispersion primarily determines the shape and width of the generated spectrum and that the fine spectral substructure exhibits extreme sensitivity to the initial pulse energy. Recent experiments from the Trebino Group at Georgia Tech have confirmed these predictions.

Lastly, we investigated femtosecond-pulse propagation through large-core MFs. Although these fibers are highly multimode, excitation of the fundamental mode is readily achieved, and coupling to higher- order modes is weak even when the fiber is bent or twisted. Such fibers have small effective nonlinearities as a result of the large mode area, and for prechirped input pulses with energies as large as 3 nJ, pulses as short as 140 fs were produced at

the output of the fiber. Such a system could prove to be extremely useful for applications such as in vivo multiphoton microscopy and endoscopy that require delivery of femtosecond pulses and collection of fluorescence.